10/533119
JC12 Rec'd PCT/PTC 29 APR 2005

Device and method for measuring capacitance and device for determining the level of a liquid using one such device

The invention relates to device for measuring capacitance as claimed in the preamble of claim 1 and a corresponding method and a device for determining the level of a liquid using one such a device.

The prior art, for example the publication of TOTH, F.N. et al.: A new capacitive precision liquid-level sensor, Digest 1996 Conference on Precision Electromagnetic Measurements, Braunschweig, discloses generic devices. Here elongated "guard" and reference potential ("E_0") electrodes are located parallel to a series of successive measurement electrodes adjacently on one side or both sides. The capacitance and thus ultimately the level are measured by measuring the capacitance between the individual measurement electrodes and the opposing elongated reference potential electrode.

These devices necessitate high complexity of interconnection and thus high production and installation costs. In addition, special precautions must be taken to achieve high resolution with low sensitivity to noise signals.

The object of the invention is to provide a device which overcomes the disadvantages of the prior art. Moreover, the pertinent process and a corresponding means for determining the level of a liquid in a container are to be made available. The device as claimed in the invention is to be especially economical to produce and install and is to be continuously reliable in operation. Resolution and (in)sensitivity to noise signals be further optimized.

This object is achieved by the device as specified in claim 1 and by the process defined in the subordinate claim and the means defined in a likewise subordinate claim for determination of the level. Special versions of the invention are defined in the dependent claims.

The object is achieved in a device for capacitance measurement with an electrode arrangement consisting of a plurality of electrodes which are located next to one another and/or in succession on a support, an actual measurement means for measuring the capacitance between a first electrode as the measurement electrode and a second electrode as the counterelectrode, and a controllable switching means for connection of the electrodes as the first and second electrodes to the measurement means, which connection can be switched in a definable manner, in that controlled by the switching means each electrode of the electrode arrangement can be switched in alternation as the measurement electrode and at least one of the other electrodes can thereby be switched as the counterelectrode to a definable reference potential.

By preference, the electrodes are located on a surface area, especially on a planar surface. In one special embodiment the electrodes are located next to one another with their longitudinal sides in a rectangle shape. The distance of the electrodes is preferably as small as possible, especially less than half, and preferably less than 1/5 of the distance from one electrode to the next. For many applications it is advantageous to arrange the electrodes on a flexible support, for example on a film of polymer plastic such as for example polyimide. The use of materials with a low temperature

coefficient of their dielectric constant, such as for example polypropylene, is especially advantageous for the flexible support and/or for a tube which optionally encloses the support.

The electrode support is preferably fixed or pressed with the electrodes into stable contact with the inner side of the tube. For example, the electrode support can be clamped onto an internal tube which is elastically deformable and which is inserted into the tube. The internal tube can be filled, especially foamed, for mechanical stabilization.

The tube, on its side facing the liquid, can be provided at least partially, preferably over its entire surface area, with a coating which, as a result of the material chosen for the coating, causes for example a high beading effect of the liquid and therefore reduces wetting with the liquid, and/or prevents diffusion of the liquid into the tube. These coatings may contain for example a polymer plastic and can be applied to the tube by painting or by an immersion bath.

Preferably the electrodes are not only electrically insulated against one another, but are also covered with an electrically insulating layer on the side facing away from the support. It is advantageous if the electrodes together with the connecting printed conductors are applied to the support in thin or thick film technology. Application can take place in a structured manner, for example by screen printing or stamping. Alternatively or in addition, application can also take place over the entire surface area and then the surface layer can be structured, for example using photolithographic structuring processes, such as are known for example from semiconductor technology or hybrid microcircuit technology.

In one special embodiment the device has a connecting means for electrical connection of other sensors and/or for connection to the switching means. The connection of other sensors and/or of the switching means takes place preferably detachably and/or if necessary sealed relative to the surrounding liquids.

Sensors may be provided which do not require direct contact with the liquids, for example a temperature sensor; in this case the sensor can be located within the tube, for example on the electrode support, and can make direct electrical contact with the printed conductors present there.

Alternatively or in addition, sensors may be provided which are to be brought into direct contact with the liquid, for example a viscosity sensor; in this case the sensor must be located outside of the tube, and electrical connection takes place by way of an electrical penetration in the tube that is impervious to fluids, especially on its bottom. Preferably there is a detachable plug connection.

Other sensors can be for example sensors for humidity, pressure or the like, or also an additional capacitive sensor with which a medium which surrounds the device is examined with respect to its dielectric constant. By preference, the connecting printed conductors for the additional sensors are also mounted on the support of the device.

Furthermore, there can also be at least parts of the controllable switching means or also the measurement means on the support of the device. As a rule, it is also possible to use as the support for the electrode arrangement the same substrate as is used for the switching means and/or the measurement means. The degree of integration of components ultimately depends on the respective application as well as the requirements for the size of the device for which there can be lower and/or upper limits dictated by the function of the device.

In one special embodiment of the invention, the definable reference potential is the ground potential of the measurement means. In this way the capacitance values of the switched electrodes can be measured especially easily in terms of circuitry and at the same time with a high degree of precision.

Preferably the so-called "charge-transfer" process is used for the measurement means. Conventional values of the capacitance to be measured, for example when using the device as claimed in the invention as a level sensor, are in the range of fractions of a pF to a few hundred pF, but can also be greater or smaller depending on the medium, especially its dielectric constant, and/or the electrode surface areas and electrode distances.

Preferably all electrodes which are not switched as measurement electrodes are switched to the reference potential, to the ground potential in particular. In the case of a level sensor it is moreover advantageous to switch the liquid and/or at least one part of the wall of the container to this or another definable reference potential.

All electrodes preferably have an essentially identical contour and surface area. Preferably all electrodes are arranged essentially equidistantly to one another and/or to the connecting lines. This yields not only simplified production of the device, but the measured capacitance values and capacitance changes are also fundamentally of the same order of magnitude. When switching through in alternation, it is moreover advantageous that the reliability of the device is increased due to the fact that the electrodes are identical. Moreover, the elongated reference potential electrode with a large surface area which is not necessary as claimed in the invention clearly reduces the surface area required by the electrode arrangement, or the electrodes can be larger with the same required surface area, whereby the measurement sensitivity and/or the measurement accuracy is increased.

To increase the measurement accuracy at a given overall size of the device, it is also possible for several electrodes which are preferably not directly adjacent to be interconnected hard-wired into one respective electrode group. Each electrode group is alternately switched as a measurement electrode, and at least one of the other respective electrode groups is switched as the counterelectrode to the definable reference potential by the switching device. This corresponds to

dividing the individual electrodes into different component segments. The hard-wired interconnection of the electrodes into the respective electrode group takes place preferably at the location of the connecting lines, especially at the height of the pertinent electrode, so that the demand for space is not increased either with respect to the connecting lines.

The invention also relates to a process for capacitance measurement using the above described device. Preferably the switching means is controlled by a microprocessor according to a control program which is stored in the microprocessor itself or in a memory component.

Moreover, the invention relates to a means for determining the level of a liquid in a container with the device described in the foregoing. In an evaluation means downstream of the actual measurement means the measured capacitance is thereby compared to the stored reference values. These reference values can be fixed and invariable, or reference values can be stored depending on the application, especially depending on the respective liquid, and optionally also depending on the signals of the other sensors, such as especially of the temperature. The stored reference values can furthermore be adapted according to a given algorithm to the current actual boundary conditions, such as for example the temperature or viscosity of the liquid.

Preferably the electrodes are arranged in succession on the support with such a means in the immersion direction. When the level is determined, the individual electrodes are initially classified into "immersed", "not immersed" and "partially immersed" in a first step using the stored reference values or fixed expected values. The result of this classification delivers discrete values, for example "0" for "not immersed", "1" for "partially immersed" , and "2" for "immersed".

An interpolation step then takes place for determining the level in the area of the partially immersed electrode. The accuracy attainable in this second, more or less analogous determination

step depends on the height h of the individual electrodes in the immersion direction and also on the characteristic of the capacitance over level.

Other advantages, features and details of the invention arise from the dependent claims and the following description, in which several embodiments are described in detail with reference to the drawings. Each of the features mentioned in the claims and in the specification may be essential for the invention singly or in any combination.

FIG. 1 shows in a simplified representation a means as claimed in the invention,

FIG. 2 shows in an enlargement the arrangement of the electrodes,

FIG. 3 shows the characteristic of the measured capacitance against ground over level,

FIG. 4 shows in an enlargement the lower end of the support,

FIG. 5 shows one alternative embodiment of the electrode arrangement,

FIG. 6 shows the characteristic of the measured capacitance against ground over level for the embodiment of FIG. 5.

FIG. 1 shows in a simplified representation a means 1 as claimed in the invention for determining the level 2 of a liquid 3 in a container 4 with the device 5 as claimed in the invention for measuring the capacitance with an electrode arrangement consisting of a plurality of electrodes E1 to En which are arranged in succession on a support 6. The device 5 furthermore has its own measurement means 8 for measurement of the capacitance between the first electrode E2 as the

measurement electrode and the second electrode E1 as the counterelectrode. Furthermore the device 5 has a controllable switching means 7 for connection of the electrodes E1 to En as the first and second electrodes E2; E1 to the measurement means, which connection can be switched in a definable manner.

The means 1 for determining the level 2 of liquid 3 furthermore comprises an evaluation means 9 which is downstream of the measurement means 8 and which determines the level 2 from the capacitance measured by the device 5 by comparison to stored reference values. This level 2 can be output and relayed from the evaluation means 9 in optional, different ways, for example using a digital display 10, voice output or a warning signal 11 by means of a speaker 12, or for further processing to a control unit 13.

The controllable switching means 7, the measurement means 8 and the evaluation means 9 are preferably integrated in a microcontroller or microprocessor, especially in a single semiconductor chip, including a memory for reference capacitance values and for the control program.

FIG. 2 shows in an enlargement the arrangement of the electrodes E1 to En; for reasons of clarity the support 6 is not shown. All electrodes E1 to En are arranged in a rectangular shape and parallel to their longitudinal sides in succession on the support 6. The lower edges of the electrodes E1 to En are marked with level heights h1 to hn. The distance of any two electrodes E1 to En is a constant h. The connecting lines L1 to Ln to the individual electrodes E1 to En are routed up to the measurement electronics, first in particular to the switching means 7. Other connecting lines 14 run parallel thereto; other sensors located on the support 6 can make contact with them, for example a temperature sensor 15 on the bottom end in the vicinity of the lowermost electrode E1.

In one preferred embodiment, the electrodes E1 to En and the connecting lines L1 to Ln are attached to a so-called flex conductor film, i.e., to a very flexible thin substrate. The flex conductor film is located in an electrically insulating tube which preferably consists of a material with a dielectric constant with a low temperature coefficient, such as for example polypropylene.

The measurement means 8 determines the capacitance between the respective first electrode E2 which is used as the measurement electrode, and at least one other electrode E1 which is positioned at the ground potential of the measurement means 8. In one special embodiment all the other electrodes which are not switched as a measurement electrode are switched to ground potential by the switching means 7.

Preferably however the electrode which is adjacent to the first electrode E2, especially adjacent underneath, is switched as the second electrode E1. Furthermore, the liquid 3 and/or, at any rate, one wall of the container 4 is also connected to the reference potential, especially connected to ground.

The capacitance of the electrodes E1 to E5 which are completely or partially immersed and which are located below the level 2 for liquids with a dielectric constant of more than one is greater at any rate than the capacitance of the electrodes E6 to En which are located above the level 2. The level 2 is determined from the measured capacitances.

The determination of the level 2 takes place in two stages: first the electrodes E1 to E4 are classified into "immersed", E6 to En into "not immersed", and E5 into "partially immersed". Then, if necessary, interpolation can be done using the capacitance value which is measured for the electrode E5 so that the exact level can be determined in the area of the partially immersed electrode E5.

FIG. 3 shows the characteristic of the measured capacitance against ground over level. The difference of the capacitance value between the "not immersed" and "immersed" state of the electrode E1 to E5 in this embodiment is approximately 2 pF at a base capacitance of approximately 150 pF. In addition to the geometrical electrode arrangement, this capacitance difference is of course dependent mainly on the dielectric constant of the liquid and accordingly in polar liquids such as water it is greater than in essentially nonpolar liquids such as oil. The characteristic of the change of capacitance in all electrodes due to the symmetrical arrangement is essentially identical and is marked by an almost linear average ascent, the start and end of which are rounded as a result of edge effects.

FIG. 4 shows in an enlargement the lower end of the support 6, which in this embodiment is made as a flex conductor film which is placed in an electrically insulating tube 16. On the lower closed end the tube 16 has an electrical plug connection 17 for electrical connection of other sensors, for example a viscosity sensor.

To increase the measurement accuracy at a given total length of the level sensor, the height h of the electrodes must be reduced. The number of electrodes would thus be increased, by which the number of signal lines L1 to Ln and also the interconnection cost would be increased.

FIG. 5 shows one alternative embodiment of the electrode arrangement of the device as claimed in the invention. Here five individual electrodes E1 to E5 are divided into two component segments E1', E1",... to E5', E5". In this way the capacitance is increased between the respective measurement electrode and the ground potential in several component stages, in this embodiment in two respective component stages. Interpolation in the second step of signal evaluation thus becomes more accurate.

The illustrated embodiment shows a total of five electrodes which are divided into two segments of the same size. Any other division is conceivable, for example also four electrodes into three respective component segments, six electrodes into four respective component segments, etc. The connecting lines of the respective component segments are connected to one another hard-wired directly on the support 6.

In this embodiment, the electrode E1 can still make contact with the two component segments E1', E1" using a single connecting line 11. The component segments E1' and E1" of the first electrode are interconnected hard-wired to form a first electrode group. This hard-wiring of the electrode groups, of which there are a total of five in the embodiment, takes place preferably both with respect to the number of electrodes combined in one group and also with respect to the relative position of the electrodes combined in one group relative to the overall electrode arrangement such that the assignment of the measured capacitance value, which is to be undertaken by the means 1 for determining the level 2, to a resulting level 2 is well-defined, ambiguities in particular are avoided.

FIG. 6 shows the characteristic of the measured capacitance against ground over level for the embodiment of FIG. 5. Observation of the current increase of the capacitance of an individual electrode E1 to E5 generally does not yield unambiguous information about the number of immersed component segments E1' to E5". It is therefore advantageous to first undertake classification into "immersed", "partially immersed", and "not immersed' for all electrodes E1 to En. This takes place preferably in that the capacitance values for "not immersed" are known or have been determined beforehand and stored. After classification of all electrodes has taken place, unambiguous assignment of the measured capacitance values to a level 2 is possible.